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GEOTECHNICAL PROPERTIES OF SOME SOILS ALONG OGUN RIVER AS EARTH DAM CONSTRUCTION MATERIALS

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Abstract

Small earth dams are important structures in the management of water resources for food security in developing nations. The construction of such dams at cheap rates depend on the availability of suitable earth material within the site location. The suitability of a given soil for use in earth dam construction is dictated by its geotechnical properties. The geotechnical properties of soils from three locations along the Ogun River in Iseyin, Nigeria, a predominantly farming community have been evaluated for their suitability as earth dam material.

Although, the liquid limit (LL) determined for the samples are in the impermeable core zone, the samples from shoku (LOC3) has the lowest LL making it most suitable soil in terms of LL. the Soil from Ogunremi (LOC1) had the highest percentage large grains while the sample from Ajambata (LOC2) had the lowest. Soils from the 3 locations fall within the permeable shell zone which implies that without further enhancement, the soils will allow seepage when used for earth dam construction. The consolidation properties showed decrease in the coefficient of compressibility and coefficient of consolidation with increase in pressure in the locations. Coefficient of consolidation was peaked at 100-200 kN/m^2 for LOC2, was least at 100-200 kN/m^2 for LOC1 and decreased linearly with increase in pressure for LOC3. Samples from LOC2 and LOC3 exhibited better coefficient of consolidation than samples from LOC1 as the pressure increased within the 100-200 kN/m^2 range. This is indicative of a relatively cohesive soil of medium shear strength.

The investigation shows that the soil from all the location would need some form of improvement to make them adequately suitable as earth materials for dam construction. Further studies, would be carried out to address these needs.

1. Introduction

Dams are constructed to impound water for diverse uses and will not be considered to be adequate in its performance if the structure is susceptible to high degree of seepage. Usually, in evaluating materials to be used in dam construction, extensive study of the engineering properties are expected and these are done in relation to different location of the material sources. Earth dams have been the most usual types of dams constructed from earliest times. Its popularity was due to the availability of earthen materials, high cost of masonry and lack of concrete then. However, earth dams still strive in modern Africa because of the ease of construction and relatively lower cost compared to other types of dams.

Soil consistency is the most critical engineering property to be considered when evaluating earth materials for dam construction. Soil consistency is related to the liquid limit (LL), plastic limit (PL) and the plasticity index (PI). Other engineering properties of equal

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importance particularly for the earth materials include the grain size distribution analysis, compaction characteristics, shear strength, consolidation characteristics and permeability.

These properties are primarily soil specific. It is the usual practice to move earth materials whose properties meet engineering standards from a location to another during construction of dams and many other engineering structures. The compromises of guidelines and standards for materials have contributed to the collapse of dams and such hydraulic structures in Nigeria in the past few years (Ogedengbe and Oke, 2006). As water from the reservoir seeps through the pores of an earth dam, seepage forces are exerted on the soil particles in the direction of the flow. Within a single embankment zone, the individual particles acted on by the seepage forces cannot move because they are held in place by neighbouring particles. At the point inside the zoned dam where the water discharges from fine materials into coarse materials however, it is possible for the finer soil particles to be washed into the void spaces of the coarser materials, and this may initiate complete dislocation in the embankments (James *et al.*, 1963) hence need for thorough compaction. Depending on the availability of suitable materials to build the embankment, the dam can be earth-fill, it can be made with one single relatively impermeable earth material (homogeneous fill), or this material can be used only for the *core* of the embankment and the flanks on either side are zones of permeable granular or rock-fill material (zoned fill) FAO (2001).

Therefore, extensive studies of geotechnical properties of soil in potential dam materials could guide in future construction decisions. In a similar study in south western Nigeria, Ogunsanwo (1985) compacted five genetically different laterite soils and noticed variation in the value of cohesion under stress condition with the parent rock. He also established that compaction procedure also influences the engineering properties of soil for construction. It is economically sensible to use earth materials from the dam site when they meet the standard criteria of quality.

Youdeowei (1986) concluded in his work on engineering characteristics of soils in certain part of Ibadan that no single sample possessed all the attributes for a good construction material. While some samples were deficient in some parameters, they were adequate in others. In such case, some procedural modifications would be necessary in the course of construction (FAO, 2001).

2. Materials and methods

This study was carried out in three locations in Iseyin area along the Ogun River which is one of the major drains of the Ogun Osun River Basin. Iseyin is located on Longitude $3^{o}30'$E and Latitude $7^{o}45'$N North of the equator (Figure 1). The area is made up of mainly crystalline rocks which fall under the migmatite-gneisis complex classification (Oyawoye, 1964). Iseyin is in the tropical wet and dry climate with well defined rainy and dry seasons. The average temperature ranges between 23 and 32 ^{o}C and rainfall in the region is about 1500 mm per annum. The location is in the derived savannah ecological zone which is a transition area between the humid southern forest and the northern sub humid guinea savannah.

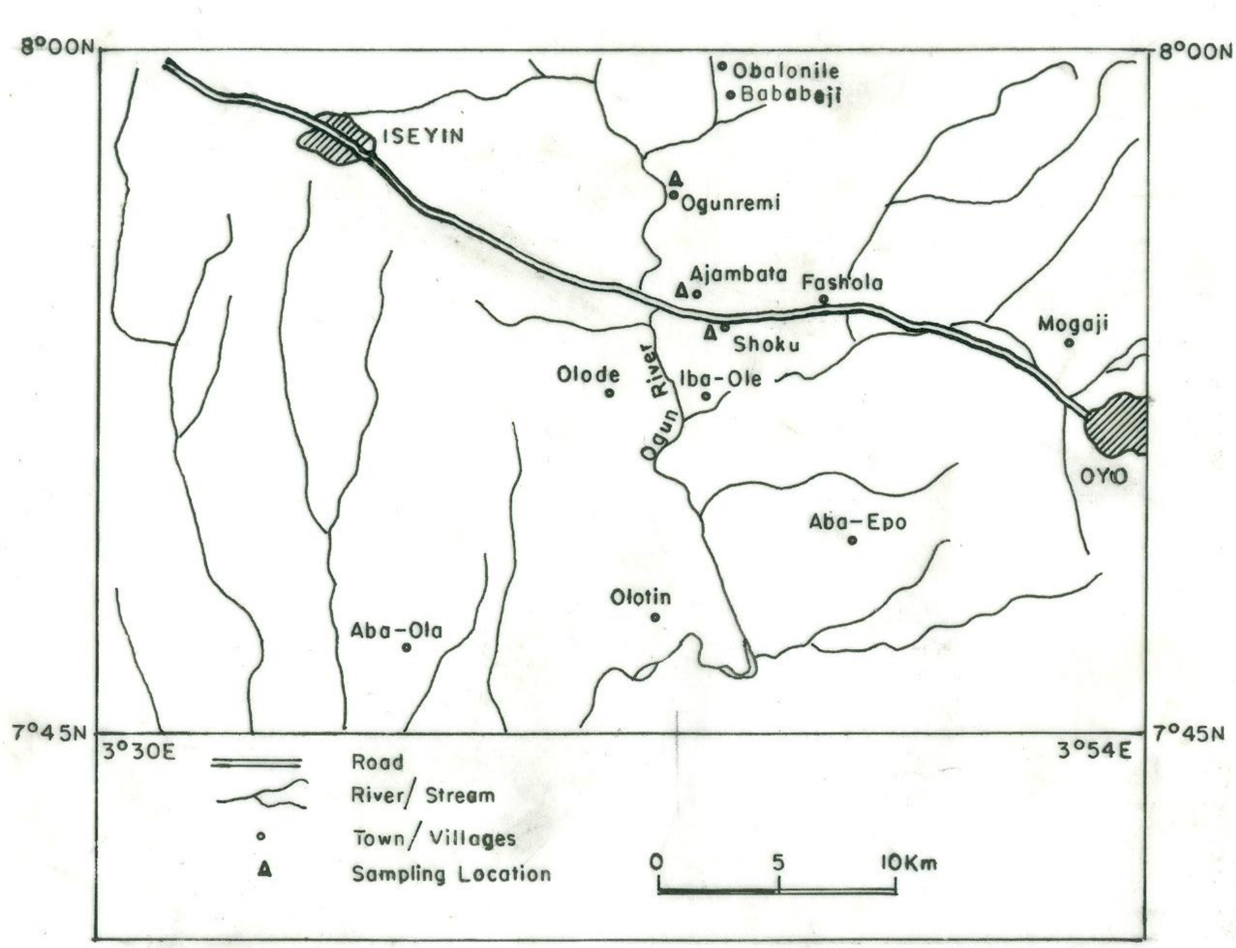

Figure 1: Map of the study area showing sampling locations

Three possible sites were located.
Location 1 (LOC 1) - Ogunremi ($3^{o}45^{'}$E, $7^{o}58^{'}$N)
Location 2 (LOC 2) - Ajambata ($3^{o}44^{'}$E, $7^{o}56^{'}$N)
Location 3 (LOC 3) - Shoku ($3^{o}44^{'}$E , $7^{o}52^{'}$N)

The soils from these locations were sampled for geotechnical quality as earth dams' materials. A total of twelve undisturbed samples were collected at the depth of 1.0 m to a maximum of 3.0 m using core cutter assisted by a steel cutter, 10 cm in diameter and 13 cm high with a dolling of 2.5 cm high.

The sieve and sedimentation analysis was carried out for particle size distribution. The liquid limit (LL) and plastic limit (PL) were determined for the samples according to McBride (2002). The plasticity index (PI) was evaluated as:

$$PI = LL - PL \quad (1)$$

The compaction characteristics were determined using cylindrical metal mould with a capacity of 1000 cm^3, internal diameter of 100 mm and effective height of 127.3 mm. The mould was fitted with a detachable base and a removable extension collar approximately 60 mm high. A 4.5 kg metal rammer with a circular face 50 mm in diameter and a drop of 450 mm was used in the compaction.

The maximum shear strengths were conducted to evaluate the shear parameters according to Atkinson (1993). Tri axial cell with transparent chamber capable of resisting internal fluid pressure of 300 kN/m^2 was used. Consolidation properties were determined using the floating ring type consolidometer (McBride, 2002). The consolidation test was to show the pressure-void relationship, coefficient of consolidation and coefficient of compressibility. Atkinson (1993) related the coefficients of consolidation and compressibility by the following equation:

$$C_v = \frac{K}{M_U \gamma_w} \quad 2$$

Where

C_v = Coefficient of consolidation
K = Permeability
M_U = Coefficient of compressibility
γ_w = Unit weight of water

Permeability tests were conducted to understand the coefficient of permeability from the three locations. The constant head permeameter was used (McBride, 2002). The guidelines for the acceptable range of properties for materials used in earth dam construction are given in Table 1.

Table 1: Guidelines to the acceptable ranges of properties for materials used in the zones of composite earth dam

Solid Parameter	Impermeable Core	Semi permeable Intermediate zone	Permeable shell zone
Grading	Fine	Medium	Coarse
LL(%)	25-40-60	<25	<20
PI(%)	10-30	<10	<5
OMC(%)	12-25	10-25	8-12
MDD(T/m)	1.40 – 1.65	1.55 – 1.75	1.65-1.90
ASR(^{0})	20-30	30-35	>35
Cohesion(KN/m^2)	25-50	25	>25
Permeability(cm/s)	1x10^{-7}	1x10^{-5}	1x10^{-3}

Key: LL – Liquid Limit; PI – Plasticity Index; OMC – Optimum Moisture Content
MDD - Maximum Dry Density; ASR – Angle Shearing Resistance
Source: Brink *et al* (1984)

3. Results and Discussion

For LOC1, the soil analysis showed that the sandy portion of the soil sample was 90%. About 95% of the grain passed through 2.0 mm sieve for the samples collected at 1.0 m depth (Table 2). The consistency limits show a slight decrease with depth. LL ranges between 37-42% while the PL was between 18-21% with the higher values recorded at shallower depth. The swelling potential is classified as medium (Table 3) because the samples from this location had a medium clay content (Table 2).

Table 2: Summary of analysis

Location	Depth of Sample(m)	Sample Number	Colour of sample	Sieve analysis % passing sieve number (mm)			Atterberge Limits			Compaction		K value (cm/s)	TRIAXIAL CONSOLIDATION				
													C	Q	P	M_U	C_U
				2.0	0.30	0.075	LL(%)	PL(%)	PI(%)	MDD (T/m^3)	OMC (%)		KN/m^2	(°)	KN/m^2	m^2/MN	m^2/yr
Location 1	1.0	1	Dirty Brown	95	70	49	42	21	21	1.66	8.5		26	10			
	2.5	2	Reddish Brown	85	52	42	37	18	19	1.93	9.5	$2.3x10^{-3}$			0-100	0.267	10.2
															100-200	0.174	7.6
															200-400	0.12	7.8
Location 2	1.2	1	Brown	66	50	43	49	25	24	1.86	12.0		16	15			
	2.0	2	Reddish Brown	89	68	56	42	20	22	1.80	15.0	$1.3x10^{-3}$			0-100	0.417	8.2
															100-200	0.14	9.1
															200-400	0.081	7.8
Location 3	1.5	1	Greyish Brown	73	47	36	37	23	14	1.81	11.8		22	7.0			
	3.0	2	Brown	79	61	52	33	23	10	1.80	14.2	$3.0x10^{-3}$			0-100	0.499	12.1
															100-200	**0.2231**	**11.5**
															200-400	**0.1346**	**8.88**

Key;
LL – Liquid limit, Plastic Limit – PL, PI – Plasticity index, OMC – Optimum Moisture Content
MDD – Maximum Dry Density
K = Co-efficient of Permeability
C = Cohession (KN/m^2)
Q = Internal friction angle (degree)
P = Pressure range (KN/m^2)
M_U = Co-efficient of compression (m^2/MN)
C_V = Co-efficient of consolidation (M^2/yr)

Table 3: Plasticity Index percentage in relation to swelling potential of earth material

Plasticity Index (PI) (%)	Swelling Potential
0-15	Low
15-25	Medium
25-35	High
>35	Very high

Source: Ola (1980)

Maximum dry density (MDD) and optimum moisture content (OMC) determines the compaction characteristics of a soil mass. The MDD ranges from 1.86 to 1.93 T/m, while the OMC is 8.5% at both depths (Table 2). The consolidation characteristics are shown in Table 4. The coefficient of consolidation and coefficient of compressibility decreases with increasing pressure (Table 4). Permeability value of 2.3 x 10^{-3} cm/s was recorded for this location, giving a silty sand condition (Table 2).

Table 4: Consolidation characteristics of samples from study locations

Location	Pressure range kN/m^2	Coefficient of Compressibility m^2/MN	Coefficient of Consolidation $m^2/year$
1	0-100	0.267	10.2
	100-200	0.174	7.6
	200-400	0.120	7.8
2	0-100	0.417	8.2
	100-200	0.140	9.1
	200-400	1.081	7.8
3	0-100	0.497	12.1
	100-200	0.223	11.5
	200-400	0.135	8.8

Cohesion of the soil sample from the 2.5 m depth was 26 kN/m^2 (Table 2) with internal friction angle of 10^0. This is relatively medium range values indicative of medium clay content.

LOC2

Fine, medium and coarse sand made up 60% of the soil samples while the fine and medium gravel component forms the remaining portion. About 66% of the sample passed through the

2.0 mm sieve while 43-56% passed through the 0.75 mm sieve. The samples in this location are less sandy but siltier compared with that of LOC1 (Table 2). Consistency limits showed little decrease with depth. The LL ranges between 42-49% while the PL ranged between 22-24% (Table 2). Even though the soils in this location had medium swelling potential, the clay content was higher than soils from LOC 1. A MDD of 1.6 T/m and 1.8 T/m were recorded at OMC of 15% and 12% respectively. These were less than the value recorded for the MDD in LOC1at lower OMC.

The permeability of soils in this location was 1.3×10^{-3} cm/s. Thus the soil of location 2 was less permeable in comparison to the soil of LOC1 with relatively higher permeability. This was because of higher grain size distribution in the location. Shear strength results from samples of this location give a cohesion value of 16 kN/m^2 and internal friction angle of 150.15^0. This is indicative of higher bearing ratio.

LOC3

The sandy portion of the soil sample was over 80%. About 80% of the grain making up the sample passed through the 2.0 mm sieve (Table 2). The LL was 37 and 33% for soils at depths of 1.5 and 3.0 m respectively. The PL was 23% at this location at the two depths. The soil was within the range of low swelling potential category (Table 3) owing to its low clay content. The MDD was 1.80 T/m for OMC of 14% and 1.81 T/m for OMC of 11.6%. The consolidation properties showed decrease in the coefficient of compressibility and coefficient of consolidation with increasing pressure (Table 4). This same pattern is exhibited by other locations. The shear strength test gave cohesion value of 22 kN/m^2 and internal friction angle of 7^0. The soils indicated a relatively cohesive soil of medium shear strength. The soils of the three locations are relatively cohesive soil of medium shear strength. Even though, the samples from the 3 locations had MDD and OMC within the range for the type of soil described from these sites (FAO 2001), none of the materials from either locations met all the geotechnical criteria as earth dam materials

Generally, soil samples from LOC 1 had highest percentage large grains while samples from LOC 2 had the lowest (Table 2). Soils from the 3 locations fall in the permeable shell zone (Table 1). This implies that without further enhancement, the soils will allow seepage when used for earth dam construction. However, the materials from location 1 were seen to be the best because they had the highest percentage of well graded large grains. This provided greater cohesion under compaction. In well graded soil, the finer particles tend to fit between the coarser particles, thus reducing the void ratios and increasing the bulk density and stability hence enhancing the load bearing capacity of the soil material. The LL determined for the samples from the locations are in the impermeable core zone (Table 1). The soils from location 3 had the lowest LL thus making them most suitable in terms of LL. Higher LL were not indication of good cohesion or better engineering properties. Samples from location 2 showed lowest permeability, thus may be less susceptible to seepage, because of the higher clay content of samples from this location.

Figure 2 revealed that the coefficient of compression decreases with increasing pressure for samples in LOC1 and LOC3, while samples in LOC2 showed increasing M_u with pressure range of 100-400 kN/m^2. This is because with samples in LOC2 with higher clay content, had higher bearing capacity. However, coefficient of consolidation was peaked at 100-200 kN/m^2 for LOC2, was least at 100-200 kN/m^2 for LOC1 and decreases linearly for LOC3 with increasing pressure. Therefore, samples from LOC2 and LOC3 have better C_v with increasing pressure within the 100-200 kN/m^2 range. This has implication for post construction consolidations of the embankment.

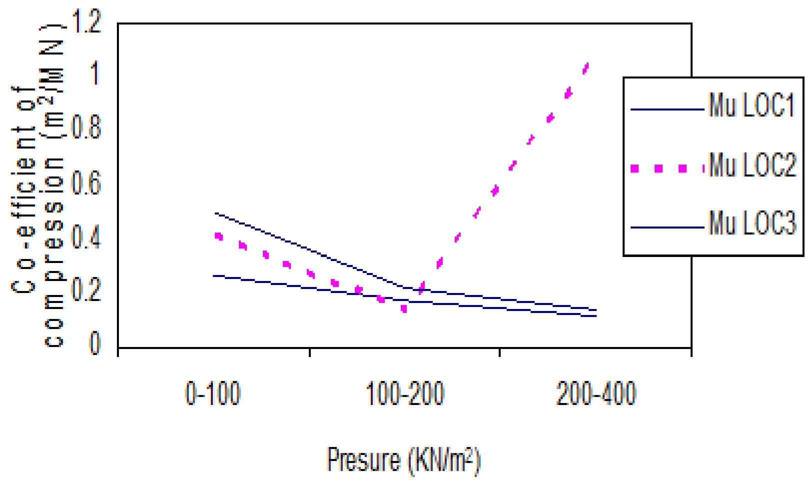

Figure 2: Coefficient of compression with pressure for the locations

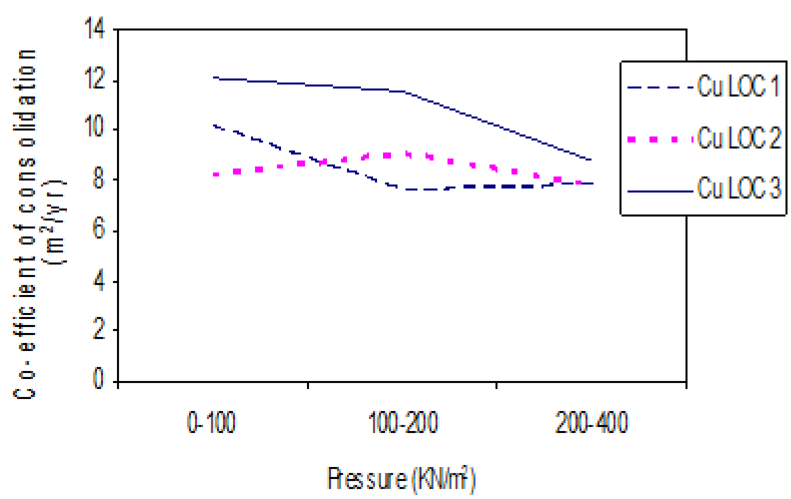

Figure 3: Coefficient of consolidation with pressure

4. Conclusion

Three locations along Ogun River in Iseyin have been evaluated with respect to Atterberg limits, particle size analysis, shear strength, permeability, compaction characteristics and consolidation properties and no single location is adequately suitable in all respects as earth material for dam construction. However, soils from all locations can be improved by artificial means such as cement stabilization, addition of lime and increase compaction. Compaction for construction should be carried out at moisture content close to the OMC so that maximum compaction would be achieved. Construction of earth dams in these potential locations may necessitate high movement of construction materials owing to the inadequacies of materials in these locations.

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